Criteria for distinguishing parthood from spatial inclusion in biological objects

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Beyond Part-Of

- Part-of / has-part: Generally accepted foundational relation to describe the spatial composition of biological organisms.
- Can the generic part-of be clearly distinguished from other relations by non-discretionary criteria?
- Is the part-of relation suitable for an ontology of biological systems?
Phagocytosis / Digestion

Virus

Cell

\[ t_1 \quad t_2 \quad t_3 \quad t_4 \quad t_5 \]
Secretion
Parthood and Spatial Inclusion

\textit{part-of}: \quad p(x, y, t) \quad \text{generic parthood relation between objects}

\textit{Region}: \quad R(z) \quad z \text{ is a region in (Euklidean) space}

\begin{align*}
z &= r(x, t) \quad z \text{ is the region where } x \text{ is located at } t \\
p(x, y, t) &\rightarrow p(r(x, t), r(y, t))
\end{align*}

\textit{Spatial inclusion} (coverage, (partly) location, ... )

\textit{si}  \textit{spatially included by}:

\begin{align*}
si(x, y, t) &= \text{def } p(r(x, t), r(y, t))
\end{align*}

(Donnelly, IJCAI 03)
When does inclusion imply parthood?

- Under which circumstances \( \phi \) can we infer parthood from spatial inclusion?

\[
si(x, y, t) \land \phi \rightarrow p(x, y, t)
\]

- Sortal constraints
- Life cycle
- Ontological Dependence
- Function
1. **Sortal Constraints**

- **x and y are regions:**  
  \[ R(x) \land R(y) \land si(x, y) \rightarrow p(x, y) \]

- **x is material, y is immaterial:**  
  \[ Solid(x) \land Hole(y) \land si(x, y) \rightarrow \neg p(x, y) \]
  - \[ si(myBrain, myCranialCavity) \rightarrow \neg p(myBrain, myCranialCavity) \]

- **x is an non-biological artifact:**  
  - \[ si(myPacemaker, myBody) \rightarrow \neg p(myPacemaker, myBody) \]
  - \[ si(myInlay, myTooth) \rightarrow \neg p(myInlay, myTooth) \]
  - \[ si(aBullet, myArm) \rightarrow \neg p(aBullet, myArm) \]
1. Sortal Constraints

- Alien organisms (and what they spatially include)
  - Symbionts:  
    - $si \ (an\text{EcoliBacterium}, \ my\text{Intestine}) \rightarrow \neg \ p \ (an\text{EcoliBacterium}, \ my\text{Intestine})$
  - Parasites:  
    - $si \ (an\text{Echinococcus}, \ my\text{Liver}) \rightarrow \neg \ p \ (an\text{Echinococcus}, \ my\text{Liver})$
  - Preys:  
    - $si \ (an\text{Elephant}, \ a\text{Snake}) \rightarrow \neg \ p \ (an\text{Elephant}, \ a\text{Snake})$
  - Embryos, Fetuses:  
    - $si \ (Leonardo, \ Caterina) \rightarrow \neg \ p \ (Leonardo, \ Caterina)$
1. Sortal Constraints

Borderline cases (I)

- Grafts, transplants, transfusions
  - **autologous:**
    - $si (mySaphenousVein, myHeart) \rightarrow \neg p (mySaphenousVein, myHeart)$
  - **homologous:**
    - $si (thisTransfusedRBC, myBlood) \rightarrow \neg p (thisTransfusedRBC, myBlood)$
  - **heterologous:**
    - $si (thisPigValve, myHeart) \rightarrow \neg p (thisPigValve, myHeart)$
1. Sortal Constraints

Borderline cases (II)

Masses and Collections

- Body Fluids (constant exchange but few discharge)
  - ... as a whole (endure over time)
  - $si (myCSF, myCNS) \rightarrow p (myCSF, myCNS)$
  - ... ad hoc (momentaneous existence)
    - $si (thisAmountOfCSF, myFourthVentricle) \rightarrow \neg p (thisAmountOfCSF, myFourthVentricle)$

- Body Secretions (periodic discharge):
  - $si (thisAmountOfUrine, myBladder) \rightarrow \neg p (thisAmountOfUrine, myBladder)$

- Other cases:
  - $si (myLung, thisVolumeOfAir)$
  - $si (thisCollectionOfLeukozytes, myGastricMucosa)$
2. Life Cycle

Which patterns allow the inference from inclusion to part?
2. Life Cycle: Case study

si (anAlaninMolecule, anAnimalBody)

- Ingested contained as ingredient of a bone, digested and used for albumin synthesis. Albumin excreted by urine.
- Ingested contained as ingredient of vegetal fibers, excreted by feces without digestion.
- Ingested, metabolized and used for collagen synthesis. Integrated in the structure of a bone.
- Synthesized in the liver, built in a hemoglobin molecule, leaves body by bleeding.
- Synthesized in the liver, built into a globulin molecule, then catabolized in a cell.
- Included in the zygote and the early embryo. Then catabolized in the maternal organism.
3. Ontological Dependency

- **Individual level**
  
x can only exist when y exists:
  
  - Boundaries, non-detachable objects:
    
    \[ si (myLiverSurface, myLiver) \rightarrow p (myLiverSurface, myLiver) \]
    
    \[ si (mySkull, MyHead) \rightarrow p (myLiverSurface, myLiver) \]
  
  - Identity-bearing Objects
    
    \[ si (myBrain, MyHead) \rightarrow p (myBrain, myHead) \]

- **Class level**

  x can only exist if an instance of the class Y exists

  \[ \forall x: \text{is-a} (x, Cell) \rightarrow \exists y: \text{is-a} (y, H_2O) \land si^1(x, y) \]

  Does not allow the inference from inclusion to part!
4. Function

- Preliminary sketch:
- If x is missing, then a function of y cannot be realized:
  Example:
  If a kidney is missing, then the filtration function of the body cannot be realized.
  Hence, a transplanted kidney, which has this function, can be considered part-of the receptor organism.
Conclusion

- Parthood implies Spatial inclusion
- What differentiates Parthood in biological organisms?
- Workflow of analyses needed:
  1. Check sortal constraints
  2. Analyze life cycle
  3. Analyse ontological dependency
  4. Analyse function (?)
- Unclear cases remain!
- Implication for biological ontologies:
  - Use Spatial inclusion as primitive instead of Parthood
  - Automatic Refinement to Parthood where the above workflow yields unambiguous results
Anatomical boundaries and immaterial objects

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Is the fly inside or outside her body?
Problem (I)

- Biological objects need clearly defined boundaries to enable assertions parthood and location
- Most Biological objects are sponge-like (full of vessels, capillaries, cavities, holes and other hollow spaces)
Many cavities communicate with the exterior space (e.g. respiratory system)

Common conceptualization (cf. biomedical terminologies): biological objects have immaterial parts, eg. Lumen of esophagus, alveolar lumen, many cavities and holes in bones, ...
How to deal with hollow spaces?

H is part of E, hence B is located outside of S

H is part of S, hence B is located inside of S
Problem

- Inside or outside?
- Example: Bronchi
  A foreign body in a bronchus is in the lung
- Strict topological view conflicts with shared conceptualization
Where to delimit?
1. All hollow spaces are part of the exterior...

... but nothing can be located inside...
2. Those hollow spaces which communicate with the exterior are part of the exterior space...

... what if some spaces only temporarily communicate?
4. The complete convex hull is part of the object...

... then the body would practically spatially coincide with the vascular system!
3. Only those hollow spaces which are containers something are part of the exterior space...

... how to ascertain whether they are containers?
Solution

... how to ascertain whether they are containers?
Algebraic Properties: *Part-Of* / *Has-Part* vs. *part-of* / *has-part*

**Instance level:**

- $\text{part-of} \ (a, b), \ \text{part-of} \ (b, c) \rightarrow \text{part-of} \ (a, c)$  
  - *Transitivity*?
- $\text{part-of} \ (a, b) \rightarrow \neg \text{part-of} \ (b, a)$  
  - *Asymmetry*
- $\text{part-of} \ (a, b) \rightarrow a \neq b$
- $\text{part-of} \ (a, b) \rightarrow \text{has-part} \ (b, a)$

**Class level*:**

- $\text{Part-For} \ (A, B), \ \text{Part-For} \ (B, C) \rightarrow \text{Part-For} \ (A, C)$
- $\text{Part-For} \ (A, B) \rightarrow \neg \text{Part-For} \ (B, A)$
- $\text{Part-For} \ (A, B) \rightarrow \neg \text{Is-A} \ (A, B)$
  - ?
- *Part-For* $(B, A)$ does not necessarily imply *Has-Part* $(A, B)$
- *Possible-Part* $(B, A)$ implies *Has-Possible-Part* $(A, B)$

(...)

*Inverse Relation*
Part-Of in Anatomies: Consensus required about

- Domain and range of part-of relations
- Algebraic properties of part-of relations
- Intended meaning of part-of relations in the domain of biology and medicine
Different notions of part-of

- Time-independent:
  - Compositional
  - Functional
  - Topological

- Time-dependent:
  - a part-of b at any point of time → a part-of b at every point of time
  - a part-of b at one point of time, a NOT part-of b at another point of time
Different notions of part-of

- **Time-independent:**
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- **Time-dependent:**
  - *a part-of* *b* at any point of time → *a part-of* *b* at every point of time
  - *a part-of* *b* at one point of time, *a NOT part-of* *b* at another point of time
Parts as Components

Parts “build” the whole

part-of (Finger, Hand)
part-of (Bone Marrow, Bone)
part-of (Sodium Ion, Cytoplasm) ?
part-of (Sarcomer, Muscle)
part-of (Heart, Human Body)

“Intuitive” notion of part. Controversial
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  - *a part-of b* at any point of time →
    *a part-of b* at every point of time
  - *a part-of b* at one point of time,  
    *a NOT part-of b* at another point of time
Parts as Functional Components

Part contributes to the function of the whole

part-of (Finger, Hand)
part-of (Lymph Node, Lymphatic System)
part-of (Cell Nucleus, Cell)
part-of (Tendon, Muscle)
part-of (Tooth, Jaw)

More restricted, may conflict with notions of connection
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instance level
Different notions of part-of

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  - Topological

- **Time-dependent:**
  - \( a \text{ part-of } b \) at any point of time \( \rightarrow a \text{ part-of } b \) at every point of time
  - \( a \text{ part-of } b \) at one point of time,
    \( a \text{ NOT part-of } b \) at another point of time
Continuous exchange of matter
Endosymbiont Hypothesis

2.5 billion years ago:
Primitive cell with bacterium-like symbionts

Today:
Chloroplasts (Plants)
Mitochondria

Are the organells part of the cell
Which eggs are part of the body?
Topological parts

Located within the boundaries of an object

part-of (Mitochondrion, Cell)
part-of (Brain, Head)
part-of (Brain, Cranial Cavity) ?
part-of (Ovum, Oviduct) ?
part-of (Finger, Hand)
part-of (Amount of Blood, Right Ventricle) ?

has-location instead of part-of ?
Topological parts

Located within the boundaries of an object

has-location (Mitochondrion, Cell)
has-location (Brain, Head)
has-location (Brain, Cranial Cavity)
has-location (Ovum, Oviduct)
has-location (Finger, Hand)
has-location (amount of Blood, Right Ventricle)

has-location as a mereotopological primitive?
Topological parts

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Example

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Different notions of part-of

- **Time-independent:**
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- **Time-dependent:**
  - \textit{a part-of } \textit{b} at any point of time \rightarrow \textit{a part-of } \textit{b} at every point of time
  - \textit{a part-of } \textit{b} at one point of time, \textit{a NOT part-of } \textit{b} at another point of time

(instance level)
Example: Transplantation

part-of (K_1, John)
part-of (K_2, John)
Example: Transplantation

part-of ($K_1$, John)
part-of ($K_2$, John)

part-of ($K_2$, Paul)
part-of ($K_2$, John)

$K_1$  $K_2$
Phagocytosis / Digestion
Secretion
Conclusion

- Part-of: example, how many different interpretations co-exist
- Standardization: need to eliminate ambiguity by precise characterization of foundational primitives (properties, relations)
- Solid theoretical basis is needed, e.g. mereotopology: Simons, Casati, Smith, Varzi,...